Endosteal biologic augmentation for surgical fixation of displaced femoral neck fractures

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Abstract: Objectives: To report outcomes of a cohort with displaced Femoral Neck Fractures (FNF) treated with a length/angle-stable construct augmented with an endosteal fibular allograft serving as a biologic dowel. Design: Prospective Setting: Level I Trauma Center Patients: The study group consists of twenty-seven patients with isolated FNF surgically treated by a single surgeon. Intervention: Open reduction of the femoral neck, fixed with a length- and angle stable-construct of two fully threated cannulated screws augmented with an endosteal fibular allograft serving as a biologic dowel. Main Outcome Measurements: Clinical and radiographic outcomes of the fixation construct and the viability of both the femoral head and the fibular allograft, host response to the allograft and osseous union was evaluated using a specialized sequence of contrast-enhanced MRI obtained at 3 and 12 months postoperatively. Results: This construct resulted in high union rates (89%; 24/27). Two patients suffered early catastrophic failure and one patient developed fracture non-union, all of wish underwent uneventful conversion to total hip arthroplasty. Three (11%) additional patients had removal of symptomatic implants. The clinical and radiographic outcomes were excellent. Twelve months MRIs revealed either partial or complete osseous incorporation of 86% the fibular allografts without signs of adverse reaction of the host to the allograft. Femoral head osteonecrosis segments were noted in 76% of patients on MRI, however radiographically there were no sign of osteonecrosis or segmental collapse. Conclusion: The fibular allograft reconstructs the comminuted femoral neck, and the osteointegration overtime increases the strength of the host-bone-graft interface. This added strength seems to provide the stability needed to better preserve the intra-operative reduction, obtain good outcomes and reduce the complications associated with FNF. Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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Endosteal Biologic Augmentation for Fixation of Displaced Femoral Neck Fractures

Lionel E. Lazaro MD[1]; Jacqueline F. Birnbaum MD[1]; Nadja A. Farshad-Amacker MD[2]
David L. Helfet MD[1]; Hollis G. Potter MD[1]; Dean G. Lorich MD[1]

[1]Hospital for Special Surgery and New York Presbyterian Hospital, New York, NY, Weill Medical College of Cornell University, New York, NY, Orthopaedic Trauma Service

[2]Institute of Diagnostic and Interventional Radiology, University Hospital of Zürich, University of Zürich, Rämistrasse 100, 8091 Zürich, Switzerland

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Corresponding Author:

Lionel E. Lazaro, MD

535 East 70th Street, New York, NY

lazarol@hss.edu

212-746-3133 (office)

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Abstract

Objectives: To report outcomes of a cohort with displaced Femoral Neck Fractures (FNF) treated with a length/angle-stable construct augmented with an endosteal fibular allograft serving as a biologic dowel.

Design: Prospective

Setting: Level I Trauma Center

Patients: The study group consists of twenty-seven patients with isolated FNF surgically treated by a single surgeon.

Intervention: Open reduction of the femoral neck, fixed with a length- and angle stable-construct of two fully threated cannulated screws augmented with an endosteal fibular allograft serving as a biologic dowel.

Main Outcome Measurements: Clinical and radiographic outcomes of the fixation construct and the viability of both the femoral head and the fibular allograft, host response to the allograft and osseous union was evaluated using a specialized sequence of contrast-enhanced MRI obtained at 3 and 12 months postoperatively.

Results: **This construct resulted in high union rates (89%; $^{24}/_{27}$). Two patients suffered early catastrophic failure and one patient developed fracture non-union, all of wish underwent uneventful conversion to total hip arthroplasty. Three (11%) additional patients had removal of symptomatic implants. The clinical and radiographic outcomes were excellent.** Twelve months MRIs revealed either partial or complete osseous incorporation of 86% the fibular allografts without signs of adverse reaction of the host to the allograft. Femoral head osteonecrosis segments were noted in 76% of patients on MRI, however radiographically there were no sign of osteonecrosis or segmental collapse.

Conclusion: The fibular allograft reconstructs the comminuted femoral neck, and the osteointegration overtime increases the strength of the host-bone-graft interface. This added strength seems to provide the

stability needed to better preserve the intra-operative reduction, obtain good outcomes and reduce the complications associated with FNF.

Key Words: displaced femoral neck fracture;fibular allograft;osteonecrosis,length-stable fixation, osteointegration

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Introduction

Successful treatment of displaced fractures of the femoral neck remains challenging(1-4). Surgical preservation of the native Femoral Head (FH) continues to be associated with high re-operation rates(20-64%)(4-10), often prompting surgeons to replace the FH instead(5, 11, 12). Major complications include fracture non-union(30%)(10), FH osteonecrosis(25-45%)(13) and late segmental collapse(25%)(14). These complications are considered secondary to biomechanical and biological limitations for fracture healing coupled with instability resulting from suboptimal reduction and/or poor biomechanical constructs(1, 4, 15, 16).

The proximal end of the femur mainly consists of a dense arrangement of cancellous bone covered by a thin cortex(17). In fractures, the thin cortical shell at the compression side is often comminuted(1, 18, 19) making perfect re-apposition difficult to achieve, particularly when attempting closed reduction(1, 4, 16, 20). Even if anatomic reduction is achieved, concern prevails on how to maintain reduction and resist forces acting on the femoral neck(1, 3, 4, 16, 17). Traditionally, in order to increase the chances for fracture healing, valgus malreduction is accepted and sliding constructs that permit dynamic compression at the fracture site during physiological loading are often employed. These constructs invariably lead to malunion and femoral neck shortening, negatively affecting hip biomechanics, outcomes and quality of life(21-25).

The ideal construct provides angle- and length-stability, withstands the forces crossing the fractured femoral neck and allows controlled microdynamization. We employed an endosteal fibular allograft, serving as a biologic dowel, to reconstruct and augment the comminuted femoral neck and provide structural support to the fully threaded screws construct.

To our knowledge, all previous fixation constructs augmented with fibular graft were sliding constructs. We evaluate the radiographic and clinical outcomes of a cohort of patient with Femoral Neck Fracture (FNF) treated with a length- and angle-stable construct augmented with endosteal fibular allograft. Using a specialized sequence of contrast-enhanced MRI, we aimed to evaluate osseous incorporation and biologic changes that occur (i) at the interface of the fibular allograft-host bone and (ii) within the fibular allograft. It was our hypothesis that the fibular allograft, serving as a biologic dowel in a length- and angle-stable construct, undergoes osseous incorporation over time and permits better preservation of intra-operative reduction, reduces complications and improves outcomes.

Patients and Methods

This prospective study was approved by our Institutional Review Board. Patients with isolated, unilateral FNF surgically treated by a single surgeon were enrolled. Exclusion criteria consisted of: (i) age <18 years, (ii) non-isolated injury and (iii) a follow up duration < 12-months. The fractures were classified either as non-displaced or displaced. The Garden classification(1) does not address sagittal plane deformity. If $\geq 20°$ of posterior roll-off was found, using the method of Palm et al(26), the fracture was classified as displaced and fracture reduction was performed. Patients were indicated for ORIF of their FNF if they were highly functional (physiologically young and able to ambulate unlimited distance without assistive device) regardless of the age to the age of 85 years. Regardless of fracture pattern, patients with significant medical co-morbidities, advanced physiologic age, degenerative changes of the FH, or pathological fractures were indicated for arthroplasty.

Surgical Technique

The surgical technique was recently described(15). This technique consists of open anatomic reduction, intraoperative compression and use of a true length- and angle-stable construct. A strategically placed endosteal fibular allograft, serving as a biologic dowel, is used to increase construct stability. The best approach to achieve anatomic reduction is through direct visualization. We preferred the Watson-Jones surgical approach(27) (Fig.1) over both the Smith-Petersen(28) and Hueter(29) surgical approaches because the latter two required two incisions, one for fracture reduction and another for implant placement; whereas the Watson-Jones approach requires a single incision.

Deformity correction in all planes is essential to achieving and maintaining the near anatomic reduction and compressing along the calcar. The construct begins with fracture compression and correction of deformity with the insertion of a 7.3mm partially threaded screw through the tension side of the fracture (inferior in valgus and superior in varus deformities) visible on the anteroposterior (AP) view and centrally in the femoral neck and head as seen on a lateral view. Next, a partially threaded screw (7.3mm) is inserted in the center of the FH, as visualized on the AP view. A track is made for the allograft fibula using a 10-11mm cannulated drill, and the fibula itself is burred to a core diameter of 10-11mm, and tapped gently into place below the subchondral bone. The fibula is strategically placed at the compression side of the fracture augmenting the comminuted neck and helping control deformity forces in both coronal and sagittal planes; superior placement for valgus deformity, and inferior placement for varus deformity. The initial partially threaded 7.3mm screws are replaced with fully threaded screws. The construct is completed using a triangulated 3.5mm compression screw which is inserted through the greater trochanter. This screw passes through the fibula and to the calcar, transfixing the fibula, and creating a fixed angle non-sliding construct between the host bone and the allograft fibula (Fig.2-3).

Clinical follow up evaluation

Range of motion hip exercises is encouraged after surgery, with strengthening beginning at 6 weeks. Patients are kept toe-touch weight bearing (20% of patient body weight) for three months, and then advanced immediately to full-weight bearing at the 3 months. Patients return for follow-up at 2 and 6 weeks, then every 3 months up to a year, and finally at 2 years. Functional assessment included Medical Outcomes Study Short Form-36 (SF-36 v.2) and Harris Hip Score (HHS)(30). The HHS scores were graded, based on Marchetti et al(31) grading system, as excellent (90-100), good (80-90), fair (70-79), or poor (≤69). Gait analysis, at their latest follow-up, was performed using the Intelligent Device Energy Expenditure and Gait Analysis

(IDEEA)(MiniSun Inc., CA, USA) portable system. This device consists of a microprocessor with five sensors secured to the subject. Gait evaluation using the IDDEA has been validated previously(32). Gait parameters evaluated included: single limb stance (SLS), cadence, cycle duration, and stride length (SL). These parameters were compared to the contralateral uninjured side.

Radiographic Assessment

Postoperative radiographs were assessed for maintenance of reduction according to Boraiah et al(33). They introduced measurements for quantification of FH migration and neck shortening, while correcting for leg rotation and magnification error. We added femoral neck offset measurements and abductor lever arm length, described by McGrory et al(34). All measurements, performed by two investigators, were compared with the uninjured hip as a control. The senior author evaluated radiographs for osseous union at every follow-up visit. The fracture was considered healed when bridging was observed on 3/4 cortices and there was no groin pain with full weight bearing.

MRI Assessment

Multi-Acquisition Variable-Resonance Image Combination (MAVRIC) MRI sequence (General Electric Health Care, Waukesha, WI) was obtained at 3 and 12 months after surgery. MRI scanning parameters are summarized in a table (see, Supplemental Digital Content 1, http://links.lww.com/BOT/A531). The MAVRIC sequence minimizes metal-induced artifact and thus improves image quality around metallic implants (35-37). An experienced musculoskeletal MRI radiologist (HGP) evaluated osseous incorporation and relative perfusion of the fibula allograft over time as well as osseous union at the fracture site. Multiple tomographic MR images were assessed on the

MAVRIC moderate echo time sequences, permitting assessment of graft incorporation immediately adjacent to the stainless steel screws. Qualitative assessment of the fibular allograft osseous-incorporation was performed using a subjective scoring system (0=none, 1=partial and 2=complete) (Fig-4). For grade 0 (no incorporation), the cortex of the allograft is well defined without any irregularities, with incorporation the outer line of the cortex gets more irregular and hyperintense, first only focally (grade 1- partial incorporation) and finally along the whole bone graft (what we defined as complete or grade 2).

Semi-quantitative assessment of the relative perfusion of the fibular allograft was performed using pre- and post-contrast enhanced images. Pre- and post-contrast Signal Intensity(SI) enhancement was measured using a standardized region of interest (ROI) within the bone marrow of the fibular allograft. The measured SI enhancements were normalized to cortical bone to correct for minor variations in center frequency and transmit/receive gain between the pre- and post-contrast acquisitions, and a percentage SI enhancement was calculated.

Statistical analysis

All statistical analysis was performed using the PRISM software (Version 6, Graphpad software, La Jolla, CA). For intergroup comparisons, a paired two-tailed student's t-test was used, reporting mean and standard deviation. Box and whisker plots display the minimum and maximum value. A p-value <0.05 was considered statistically significant. Statistics for continuous variables were calculated in terms of means and standard deviations and for categorical variables frequencies and percentages were used.

Results

Patients

Thirty-seven patients with FNF presented at our institution between October-2009 to July-2013, five were indicated for primary THR and five (non-displaced fractures) underwent closed reduction and percutaneous pining. The other twenty-seven patients (8 males and 19 females) met inclusion criteria. At time of surgery average patient age was 59.9 years (range of 29-84), with 9 patients ≥ 65 years and 4 patients ≤ 50 years. Pre-injury, all patients were physiologically young, highly functional and able to ambulate unlimited distance without need of assistive devices. Average follow-up was 17.4 ±6.6 months (one patient came for evaluation 1 month prior to her one year follow-up visit). Nineteen (70%; $^{19}/_{27}$) patients suffered a low energy mechanism of injury. All fractures were classified as displaced/unstable fractures (AO/OTA: 31-B3). Twenty-five were Garden III/IV and two were Garden I but with >20° of posterior roll-off. There were two (displaced fractures-Garden III/IV) early catastrophic failures (7%; $^{2}/_{27}$). One patient (52 year-old female, Garden IV) was non-complaint with weight bearing restrictions three weeks after fixation and the other (64 year-old female, Garden IV) suffered a fall 4 weeks after fixation. Both patients fractured the fibular allograft, and progressively developed severe varus collapse and joint penetration of the allograft. Both underwent uncomplicated Total Hip Arthroplasty (THA). Twenty five patients maintained fixation past the 3-months period of limited weight bearing status. One of those patients (4%; $^{1}/_{25}$) developed fracture non-union, 8 months after initial fixation and underwent an uneventful THA. The remaining twenty four (89%; $^{24}/_{27}$) patients achieved osseous union at an average of 16 ±4.9 weeks.

Clinical follow up evaluation

Twenty-two patients completed the functional outcome questionnaires. Average HHS scores revealed excellent outcomes (91 ±13.2). The average Mental and Physical SF-36 sub-scores were 52.9 ±11.8 and 50.5 ±8.3, respectively. Both sub-scores are above average values for normal age-matched control adults. All patients demonstrated normal gait without need for assistive devices at latest follow-up. Gait analysis data was obtained for 20 patients at latest follow-up. Patients on average recovered 98% of single-limb stance time, 100% of cadence, 96% of cycle duration, and 98% in stride length compared with uninjured side.

Radiographic Assessment

Near anatomic reduction (<5˚ difference in neck-shaft angle compared to contralateral side and <2 mm step-off) was achieved in all. The average displacement of the center of the FH compare favorable to historical control using a length-stable construct(33)(0.62±2.81mm inferiorly, 0.92 ±2.75mm medially, and 0.7˚ of increased varus versus historical data of 0.86mm, 1.23mm and 0.6˚). Average femoral neck collapse was less than that of historical controls (0.55±2.7mm versus 1.98mm). The average difference in femoral neck offset and abductor lever arm length was 3.05 ±5.08mm and 1.29 ±6.27mm, respectively. In three patients, a side plate was used to buttress and secure the fibular allograft. All three patients underwent removal of symptomatic implants; the remaining twenty-two patients did not have a buttressing side plate, and did not demonstrate symptoms related to the implant. No patient demonstrated signs of osteonecrosis on the most recent radiographs (average 19 months; range 12-30 months).

Qualitative 3-month MRI assessment revealed partial osseous-incorporation of the fibular graft in 57% ($^{12}/_{21}$) of patients. At 12-months 86% revealed either partial (29%; $^{6}/_{21}$) or complete (57%; $^{12}/_{21}$) osseous-incorporation. Osseous union at the fracture site, based on 3-month MRI, was noted to be partial in 38% ($^{8}/_{21}$) of patients and complete in the remaining 62%($^{13}/_{21}$) of patients. The 12-month MRI for all patients demonstrated complete osseous union. Quantitative assessment revealed a significant increase in percentage SI enhancement within the fibular allograft when compared to the ilium and femoral diaphysis at the 12-month MRI (Fig-5). Osteonecrosis (average size of 5.84 ±5.4cm^3) and associated sub-chondral collapse (average of 0.6 ±1.06mm) was noted in 76% ($^{16}/_{21}$) and 38% ($^{8}/_{21}$) of patients at the 12 month MRI, respectively. No MRI signs of adverse reaction of the host (synovitis, peri-allograft edema or osteolysis) to the allograft were observed in any patient.

Discussion

Displaced FNF continues to pose challenges for surgical reduction and fixation due to their inherent instability, difficulty in consistently achieving a stable construct, and maintaining reduction. Traditional fixations (sliding constructs) accept malreduction and jeopardize hip biomechanics in order to maximize the potential for fracture healing. Adherence to this fixation continues to be associated with unacceptable complications and high reoperation rates. We increase the stability of the fixation construct through augmentation with a fibular allograft acting as a biologic dowel. Our data demonstrates high union rates, minimal femoral neck shortening, low re-operation rate and excellent outcomes. Based on our MRI findings, the fibular allograft undergoes biologic changes indicative of osseous-incorporation and revascularization over time. These changes may translate into a construct that increases in strength/stability at the host bone-allograft interface over time.

Our study has limitations. The study group is small, limiting the power of the study to identify predictors of outcomes. However, we believe the primary purpose of the study, to evaluate the clinical and radiographic outcomes of this construct was still achieved. We recognize a longer follow-up is needed to fully assess FH viability. However, at the latest follow-up, no radiographic evidence of segmental collapse was noted in any patient. This clinical series did not have a control group, however, given the reported sub-optimal outcomes with the application of the commonly used sliding constructs; the authors did not offer that treatment method. Additionally, we rely on indirect measures, using advanced imaging, to evaluate biologic changes of the allograft over time indicative of viability. Additional studies with more direct measures (histological) are needed to further validate our findings, but these are not feasible in clinical practice outside an animal model. However, the MAVRIC MRI provides an excellent non-invasive method of visualizing and evaluating the allograft and host reaction over time.

In 1961, Garden(1) proclaimed the solution for this difficult problem relies on both anatomical reduction and increased stability of fixation. To improve stability and increase chances of fracture healing, surgeons often rely on valgus malreduction which negatively affects the fate of the FH(14, 38). Rotatory malposition and valgus malalignment interrupt perfusion from the foveolar arterial system affecting the already tenuous blood supply(39, 40). Late segmental collapse only occurs with severe malreduction following osseous union, suggesting that a remodeling process secondary to hip joint incongruity may be an important part of the etiology(14). In 1971, Garden(14) challenged the conventional wisdom that impaired vascularity of the FH is the main cause for failure following fixation of FNF. He stated that the quality of reduction and stability of the construct are the most important factors affecting the outcomes.

The femoral neck periosteum lacks the cambium layer and the ability to form periosteal callus (41-43), limiting fracture healing to direct/primary bone healing and thus requiring stable fixation. Traditional constructs allow sliding and dynamic compression at the fracture site, creating motion and increased strain, negatively affecting primary/direct bone healing and revascularization. This type of fixation leads to unacceptably high rates of non-union (30%)(10), varus collapse (>5˚; 39%)(24, 44) and re-operation (35%)(45). Several randomized studies have compared different configurations of sliding-constructs, and did not find any construct to be superior(5, 46-51). Additionally, these sliding constructs consistently lead to malunion with shortening of the femoral neck (>5mm)(30%-66%)(23, 24, 52). Shortening of the neck decreases the abductor moment arm and FH-neck offset, diminishing adductor muscle strength and restricting range of motion due to trochanteric impingement(34). A recent study reported that malunion of FNF resulted in a 75% prevalence of radiographic Cam-type impingement(25). In our study, patients essentially maintained the initial intra-operative reduction, femoral neck length and offset, and abductor lever arm, corresponding to excellent functional and radiographic outcomes.

During the 1940's, both King(53) and Patrick(54), augmented the Smith-Petersen nail treatment with an endosteal fibular autograft and reported decreased rates of both fracture non-union and FH osteonecrosis. Nagi el al(55, 56) had similar reports when augmenting 3 partially threaded screws with a fibular autograft in the treatment of both acute and delayed FNFs. With increased attention on preservation of the functional anatomy of the hip joint, a non-sliding construct using fully threaded screws was employed in 54 FNF, resulting in high union rates with minimal femoral neck shortening(33). A posterolateral proximal femoral locking plate using multiple, nonparallel converging/diverging screws was employed in 18 FNF in order to minimize shortening of the femoral neck (57). Unfortunately, this construct resulted in poor outcomes and high rates of catastrophic failure (37%). These failures have been attributed to the increased stiffness which may prevent fracture micromotion and dynamization, placing a mechanical stress on the implants**.** Recognizing from these failures, a small amount of motion and dynamization is necessary to avoid catastrophic implant failure seen in the rigid fixed angle plate design. To increase the strength/stability we augmented the fully threaded screw construct with an endosteal fibular allograft. The allograft is placed on the comminuted compression side of the fracture in order to rebuild the femoral neck and provide increased stability at the fracture site. The strength of the bone-screw interface weakens over time(54, 55, 58); however, the allograft undergoes osseous-incorporation(58) increasing the strength of the host bone-allograft interface and the overall stability. This construct seems to allow an extremely controlled dynamization at the fracture site in the acute phase where the graft edges are smooth, with time the graft incorporates to the adjacent bone increasing the strength of the graft-bone interface and stability of the construct.

There are concerns with use of allograft with regards to infection risk, cost and effect on salvage operations. The reported bacterial infection risk is 12%(21, 22) for massive allografts and 0.7%(21, 23) for non-massive allografts. Additionally, our MRI data did not demonstrate signs of adverse host reaction. With regard to the cost, the listed price of a 7.3mm screw is approximately $350, in the construct is replaced with a 10cm fibular allograft at a cost of $700. Traditional constructs may be less expensive in the short run but if a re-operation is needed the health care costs become significantly higher. Lastly, we do not anticipate any issue in the event that conversion to a THA, as the fibula dowel's track is 11mm, centrally smaller than the bone hole created by a DHS barrel in the lateral cortex. In our series, we had 3 patients successfully converted to THA without complication.

Conclusion

With increased attention on preservation of hip function and patient expectations, it is imperative to restore hip anatomy. Fracture reduction and fixation stability seems to be most important in avoiding complications and reoperation following fixation of FNF. We addressed the issues of instability by employing a fibular allograft, serving a biologic dowel, to increase strength of the host-bone interface over time, provide length- and angle-stability, and control deforming forces.

The increased fixation stability seems to enhance osseous union and revascularization of the FH preventing the most feared complications. The use of allograft is an attractive alternative that obviates the need of adding additional iatrogenic insult when harvesting the graft, while providing the benefits of a structural biologic graft. This type of biologic implant may improve surgical fixation of FNF. This construct should be used in a select group of patients that can follow a strict postoperative protocol with limited weight bearing status to prevent early fixation failure.

References

1. Garden RS. Low-angle fixation in fractures of the femoral neck. *Journal of Bone and Joint Surgery Br*. 1961;43:647-663.

2. Banks HH. Factors Influencing the Result in Fractures of the Femoral Neck. *The Journal of Bone & Joint Surgery*. 1962;44:931-964.

3. Bhandari M, Tornetta P, 3rd, Hanson B, et al. Optimal internal fixation for femoral neck fractures: multiple screws or sliding hip screws? *J Orthop Trauma*. 2009;23:403-407.

4. Chua D, Jaglal SB, Schatzker J. Predictors of early failure of fixation in the treatment of displaced subcapital hip fractures. *J Orthop Trauma*. 1998;12:230-234.

5. Miyamoto RG, Kaplan KM, Levine BR, et al. Surgical management of hip fractures: an evidence-based review of the literature. I: femoral neck fractures. *J Am Acad Orthop Surg*. 2008;16:596-607.

6. Masson M, Parker MJ, Fleischer S. Internal fixation versus arthroplasty for intracapsular proximal femoral fractures in adults. *Cochrane Database Syst Rev*. 2003:Cd001708.

7. Roden M, Schon M, Fredin H. Treatment of displaced femoral neck fractures: a randomized minimum 5-year follow-up study of screws and bipolar hemiprostheses in 100 patients. *Acta Orthop Scand*. 2003;74:42-44.

8. Parker MJ, Khan RJ, Crawford J, et al. Hemiarthroplasty versus internal fixation for displaced intracapsular hip fractures in the elderly. A randomised trial of 455 patients. *J Bone Joint Surg Br*. 2002;84:1150-1155.

9. Puolakka TJ, Laine HJ, Tarvainen T, et al. Thompson hemiarthroplasty is superior to Ullevaal screws in treating displaced femoral neck fractures in patients over 75 years. A prospective randomized study with two-year follow-up. *Ann Chir Gynaecol*. 2001;90:225-228.

10. Lu-Yao GL, Keller RB, Littenberg B, et al. Outcomes after displaced fractures of the femoral neck. A meta-analysis of one hundred and six published reports. *J Bone Joint Surg Am*. 1994;76:15-25.

11. Macaulay W, Pagnotto MR, Iorio R, et al. Displaced femoral neck fractures in the elderly: hemiarthroplasty versus total hip arthroplasty. *J Am Acad Orthop Surg*. 2006;14:287-293.

12. Schmidt AH, Leighton R, Parvizi J, et al. Optimal arthroplasty for femoral neck fractures: is total hip arthroplasty the answer? *J Orthop Trauma*. 2009;23:428-433.

13. Nikolopoulos KE, Papadakis SA, Kateros KT, et al. Long-term outcome of patients with avascular necrosis, after internal fixation of femoral neck fractures. *Injury*. England; 2003:525-528.

14. Garden RS. Malreduction and avascular necrosis in subcapital fractures of the femur. *J Bone Joint Surg Br*. 1971;53:183-197.

15. Lorich D, Lazaro L, Boraiah S. *Master Technique in Orthopaedic Surgery: Femoral Neck Fracture Open Reduction and Internal Fixation*. Philadelphia, PA: Lippincott Williams & Wilkins; 2013.

16. Weinrobe M, Stankewich CJ, Mueller B, et al. Predicting the mechanical outcome of femoral neck fractures fixed with cancellous screws: an in vivo study. *J Orthop Trauma*. 1998;12:27-36; discussion 36-27.

17. Garden RS. THE STRUCTURE AND FUNCTION OF THE PROXIMAL END OF THE FEMUR. *Journal of Bone & Joint Surgery, British Volume*. 1961;43-B:576-589.

18. Garden RS. STABILITY AND UNION IN SUBCAPITAL FRACTURES OF THE FEMUR. *J Bone Joint Surg Br*. 1964;46:630-647.

19. Kauffman JI, Simon JA, Kummer FJ, et al. Internal fixation of femoral neck fractures with posterior comminution: a biomechanical study. *J Orthop Trauma*. 1999;13:155-159.

20. Cleveland M, Fielding JW. A continuing end-result study of intracapsular fracture of the neck of the femur. *J Bone Joint Surg Am*. 1954;36-a:1020-1030.

21. Tidermark J, Ponzer S, Svensson O, et al. Internal fixation compared with total hip replacement for displaced femoral neck fractures in the elderly. A randomised, controlled trial. *J Bone Joint Surg Br*. 2003;85:380-388.

22. Gurney B, Mermier C, Robergs R, et al. Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. *J Bone Joint Surg Am*. 2001;83-A:907-915.

23. Zlowodzki M, Ayieni O, Petrisor BA, et al. Femoral neck shortening after fracture fixation with multiple cancellous screws: incidence and effect on function. *J Trauma*. 2008;64:163-169.

24. Zlowodzki M, Brink O, Switzer J, et al. The effect of shortening and varus collapse of the femoral neck on function after fixation of intracapsular fracture of the hip: a multi-centre cohort study. *J Bone Joint Surg Br*. 2008;90:1487-1494.

25. Wendt M, Cass J, Trousdale R. Incidence of Radiographic Cam-Type Impingement in Young Patients (<50) After Femoral Neck Fracture Treated with Reduction and Internal Fixation. *HSS Journal ®*. 2013;9:113-117.

26. Palm H, Gosvig K, Krasheninnikoff M, et al. A new measurement for posterior tilt predicts reoperation in undisplaced femoral neck fractures: 113 consecutive patients treated by internal fixation and followed for 1 year. *Acta Orthop*. England; 2009:303-307.

27. Watson-Jones R. Fractures of the neck of the femur. *British Journal of Surgery*. 1936;23:787-808.

28. Smith-Petersen MN. Approach to and exposure of the hip joint for mold arthroplasty. *J Bone Joint Surg Am*. 1949;31a:40-46.

29. Hueter C. *Funfte abtheilung: die verletzung und krankheiten des huftgelenkes, neunundzwanzigstes capitel.* Leipzig: FCW Vogel; 1883.

30. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am*. 1969;51:737-755.

31. Marchetti P, Binazzi R, Vaccari V, et al. Long-term results with cementless Fitek (or Fitmore) cups. *J Arthroplasty*. 2005;20:730-737.

32. Gardner MJ, Barker JU, Briggs SM, et al. An evaluation of accuracy and repeatability of a novel gait analysis device. *Arch Orthop Trauma Surg*. 2007;127:223-227.

33. Boraiah S, Paul O, Hammoud S, et al. Predictable healing of femoral neck fractures treated with intraoperative compression and length-stable implants. *J Trauma*. 2010;69:142-147.

34. McGrory BJ, Morrey BF, Cahalan TD, et al. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. *J Bone Joint Surg Br*. 1995;77:865-869.

35. Koch KM, Brau AC, Chen W, et al. Imaging near metal with a MAVRIC-SEMAC hybrid. *Magn Reson Med*. 2011;65:71-82.

36. Hayter CL, Koff MF, Shah P, et al. MRI after arthroplasty: comparison of MAVRIC and conventional fast spin-echo techniques. *AJR Am J Roentgenol*. 2011;197:W405-411.

37. Koch KM, Hargreaves BA, Pauly KB, et al. Magnetic resonance imaging near metal implants. *J Magn Reson Imaging*. 2010;32:773-787.

38. Walmsley T. THE ARTICULAR MECHANISM OF THE DIARTHROSES. *The Journal of Bone & Joint Surgery*. 1928;10:40-45.

39. Der schenkelhalsbruch: Ein mechanisches Problem. By Dr. Friedrich Pauwels (Aachen). Royal 8vo. Pp. 157, with 186 illustrations. 1935. Stuttgart: Ferdinand Enke. Paper covers, RM. 13.60; bound, RM. 15.00. *British Journal of Surgery*. 1936;23:874-874.

40. Smith FB. Effects of Rotatory and Valgus Malpositions on Blood Supply to the Femoral Head Observations at Arthroplasty. *The Journal of Bone & Joint Surgery*. 1959;41:800-815.

41. Frangenheim P. Studien uber Schenkelhalsgrakturen und die Vorgange bei ihrer Heilung. Dsch. Z. Chir.; 1906:401-455.

42. Schmorl G. *Die Pathologische Anatomie der Schenkelhalsbrakturen*. Munchen.Med.Wschr; 1924.

43. Banks HH. Tissue response at the fracture site in femoral neck fractures. *Clin Orthop Relat Res*. 1968;61:116-128.

44. Mir HR, Edwards P, Sanders R, et al. Results of cephallomedullary nail fixation for displaced intracapsular femoral neck fractures. *J Orthop Trauma*. 2011;25:714-720.

45. Bhandari M, Devereaux PJ, Swiontkowski MF, et al. Internal fixation compared with arthroplasty for displaced fractures of the femoral neck. A meta-analysis. *J Bone Joint Surg Am*. 2003;85-A:1673-1681.

46. Parker MJ, Stockton G. Internal fixation implants for intracapsular proximal femoral fractures in adults. *Cochrane Database Syst Rev*. 2001:Cd001467.

47. Benterud JG, Husby T, Nordsletten L, et al. Fixation of displaced femoral neck fractures with a sliding screw plate and a cancellous screw or two Olmed screws. A prospective, randomized study of 225 elderly patients with a 3-year follow-up. *Ann Chir Gynaecol*. 1997;86:338-342.

48. Paus A, Gjengedal E, Hareide A, et al. Dislocated fractures of the femoral neck treated with von Bahr screws or hip compression screw. Results of a prospective, randomized study. *J Oslo City Hosp*. 1986;36:55-61.

49. Madsen F, Linde F, Andersen E, et al. Fixation of displaced femoral neck fractures. A comparison between sliding screw plate and four cancellous bone screws. *Acta Orthop Scand*. 1987;58:212-216.

50. Kuokkanen H, Korkala O, Antti-Poika I, et al. Three cancellous bone screws versus a screw-angle plate in the treatment of Garden I and II fractures of the femoral neck. *Acta Orthop Belg*. 1991;57:53-57.

51. Parker MJ, Blundell C. Choice of implant for internal fixation of femoral neck fractures. Meta-analysis of 25 randomised trials including 4,925 patients. *Acta Orthop Scand*. 1998;69:138-143.

52. Weil YA, Khoury A, Zuaiter I, et al. Femoral neck shortening and varus collapse after navigated fixation of intracapsular femoral neck fractures. *J Orthop Trauma*. 2012;26:19-23.

53. King T. The Closed Operation for Intracapsular Fractures of the Femoral Neck. Final Results in Recent and Old Cases. British J. Surg.; 1939:721-748.

54. Patrick J. Intracapsular fractures of the femur treated with a combined Smith-Petersen nail and fibular graft. *J Bone Joint Surg Am*. 1949;31a:67-80.

55. Nagi ON, Gautam VK, Marya SK. Treatment of femoral neck fractures with a cancellous screw and fibular graft. *J Bone Joint Surg Br*. 1986;68:387-391.

56. Nagi ON, Dhillon MS, Goni VG. Open reduction, internal fixation and fibular autografting for neglected fracture of the femoral neck. *J Bone Joint Surg Br*. 1998;80:798-804.

57. Berkes MB, Little MT, Lazaro LE, et al. Catastrophic Failure After Open Reduction Internal Fixation of Femoral Neck Fractures With a Novel Locking Plate Implant. *J Orthop Trauma*. 2012.

58. Nagi ON, Dhillon MS, Aggarwal S. The long term fate of the fibula when used as an intraosseous graft. *Acta Orthop Belg*. 2004;70:322-326.

Figures Legends

Fig. 1

Drawing illustrating the Watson-Jones surgical approach. The interval between the gluteus medius and facialata muscles is developed, exposing the anterior capsule via a sharp Z-shaped incision along the anterolateral axis of the femoral neck. The capsulotomy remains anterior to the lesser trochanter at all times to avoid damage to the femoral head blood supply.

[Reprinted with permission from Lorich DG, Lazaro LE, Boraiah S. Masters Techniques in Orthopaedic Surgery: Fractures. 3rd Edition. Edited by Wiss D.In Press 2012. ISBN 9781451108149 Figure 15-3]

Fig. 2

(a)AP and lateral radiograph of a displaced femoral neck fracture. (b) Intraoperative fluoroscopic images demonstrating correction of coronal plane deformity (valgus). Terminally threaded guide wires are used as a joystick to control fragments and achieve anatomical reduction. The bull stick pusher is used to control deforming forces in the sagittal plane. (c)Fluoroscopic view demonstrating the cannulated drill used to form the track for the fibula allograft. A burr is used to contour the biologic implant to a core diameter of 10-11mm. The implant is tapped gently into the subchondral bone. The partially threaded screws are then replaced with fully threaded screws. (d)To transfix the biologic implant in place, a 3.5 compression screw is inserted through the greater trochanter, passing through the fibula to the calcar. AP (left) and Lateral (Right) views demonstrating the final length- and angle-stable construct using allograft fibula as a biologic implant.

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Fig. 3

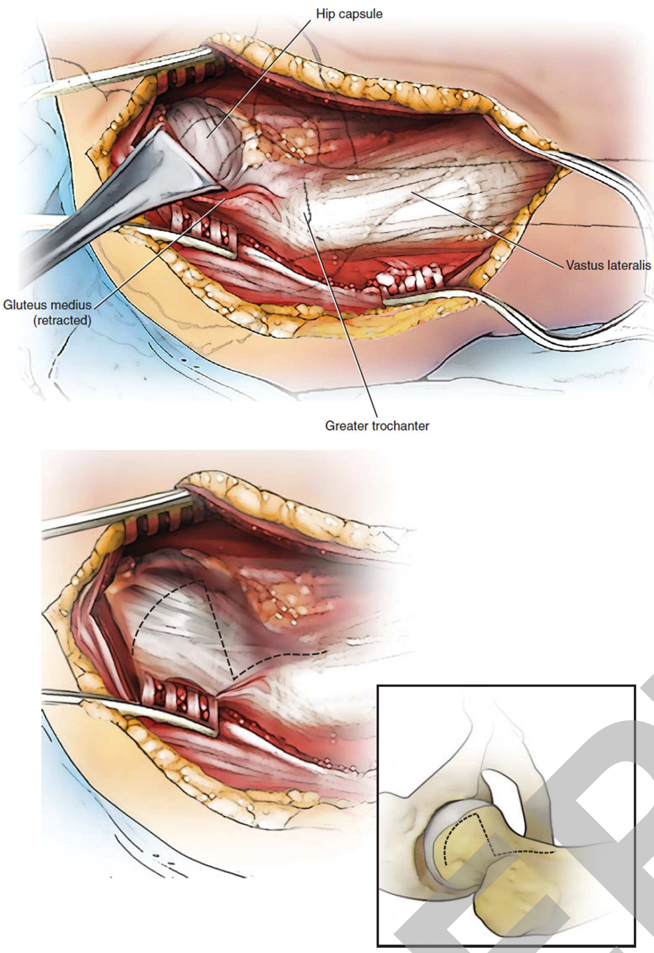
a)Anteroposterior (AP) and lateral radiographic views of a 54 year-old male who suffered a displaced femoral neck fracture with varus displacement and significant posterior roll-off. (b) AP and lateral radiographic views at 3 months follow-up demonstrating an angle- and length-stable fixation construct with use of a strategically placed fibula allograft (at the compression side of the fracture). (c) AP and lateral radiographic views at 12 months follow-up demonstrating maintenance of anatomic reduction, femoral neck length and hip joint space without radiographic signs of femoral head osteonecrosis and segmental collapse.

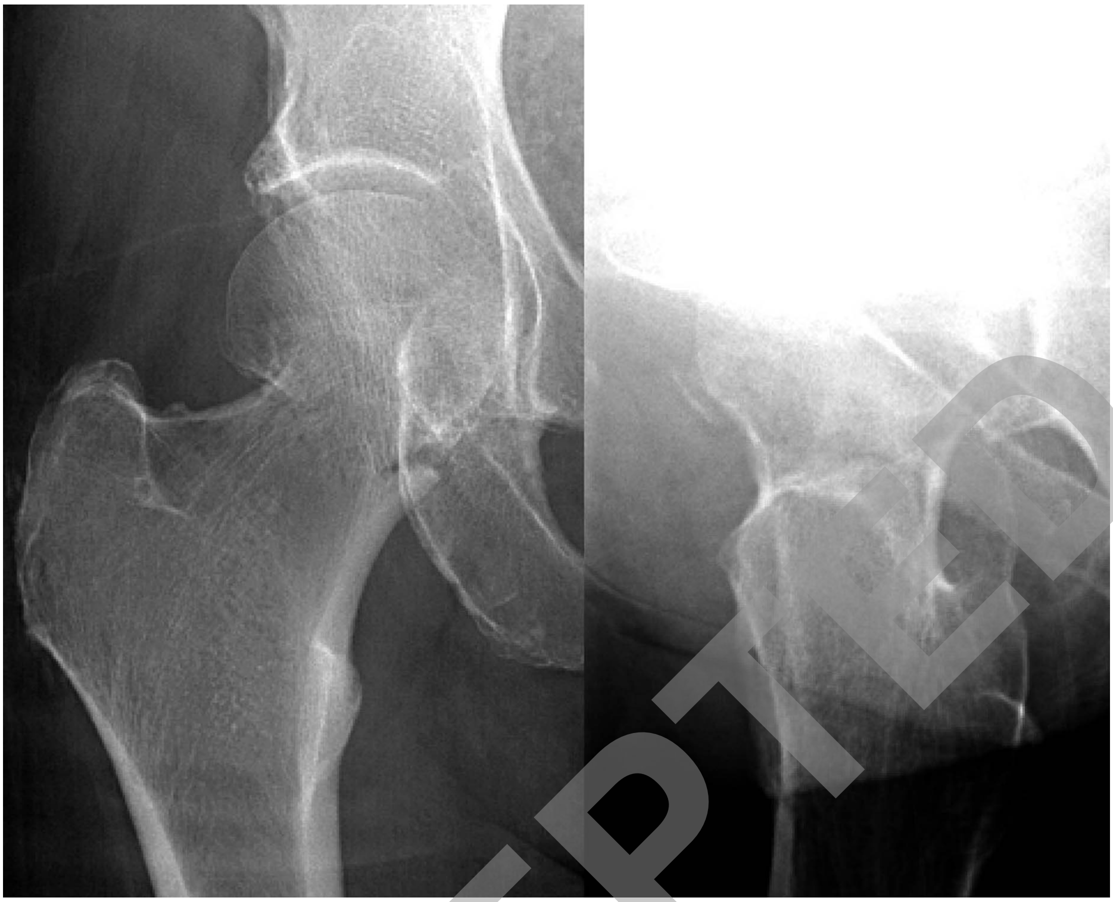
Fig. 4

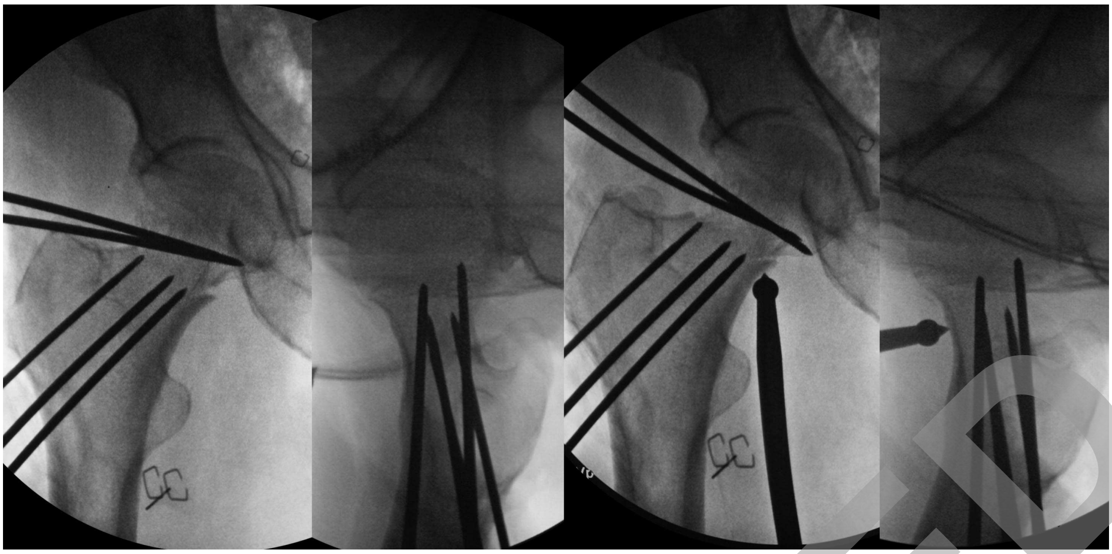
Depict the osseous incorporation scoring system based on MRI (0=none, 1=partial and 2=complete).

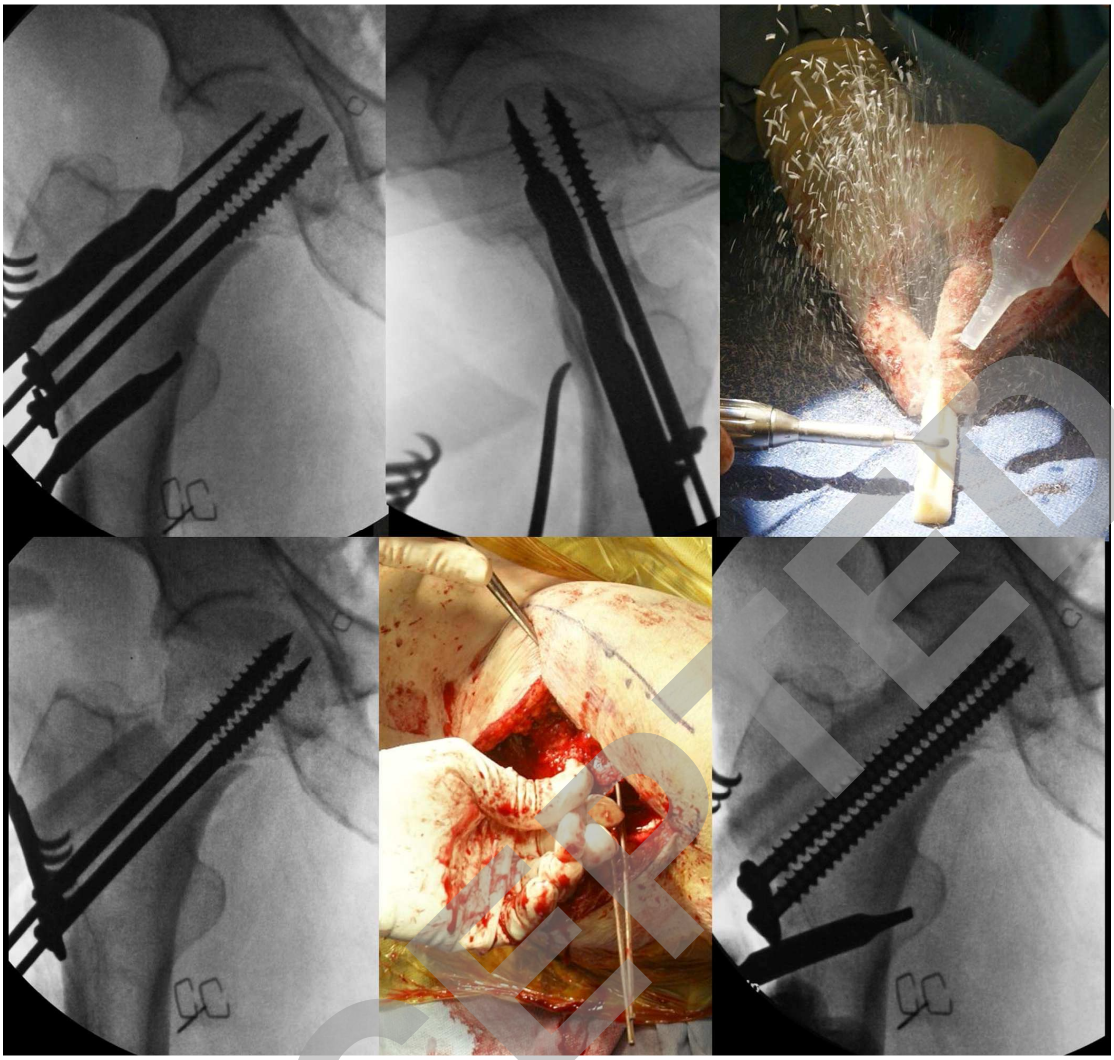
Fig. 5

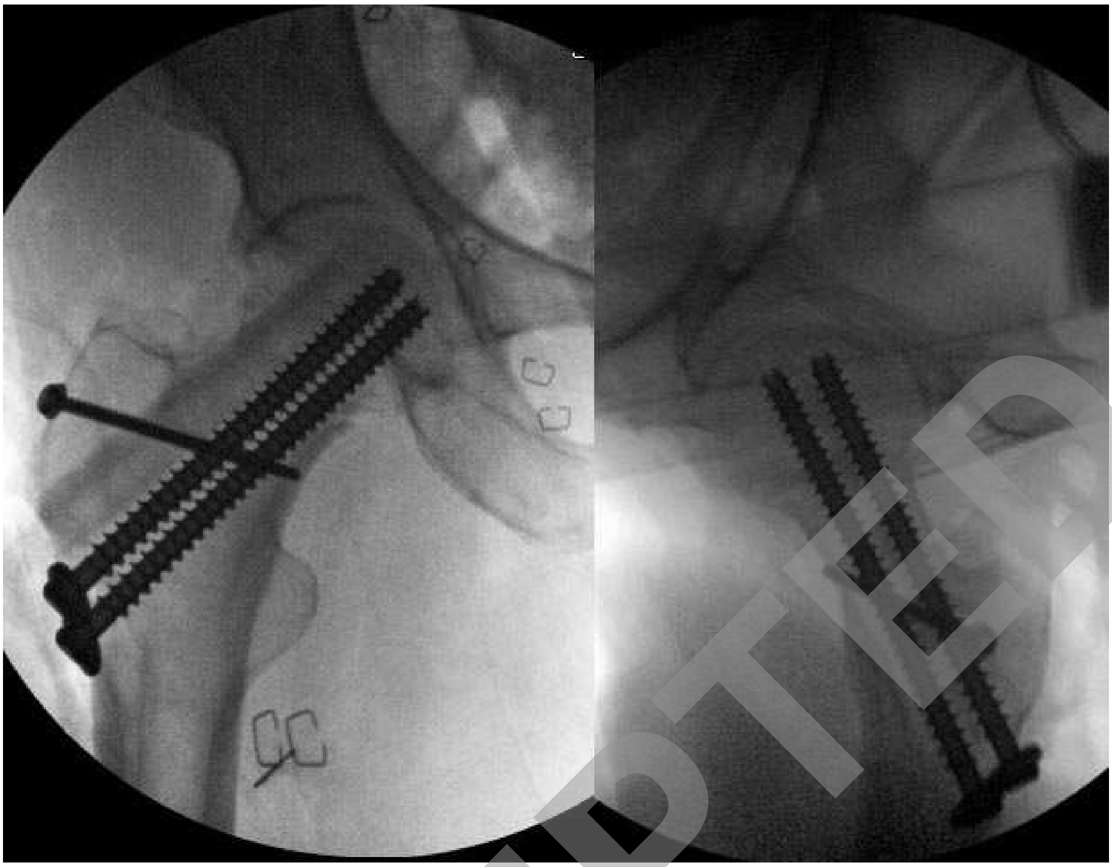
Depict a representative patient pre- and post-contrast enhanced MAVRIC images. A standard region of interest (ROI) within the bone marrow of the allograft was used to measure signal intensity enhancement. Box and whisker plots display the significant increase in signal intensity enhancement within the fibular allograft when compared to the ilium and femoral diaphysis at 12 months post-operatively. A p-value <0.05 was considered statistically significant.

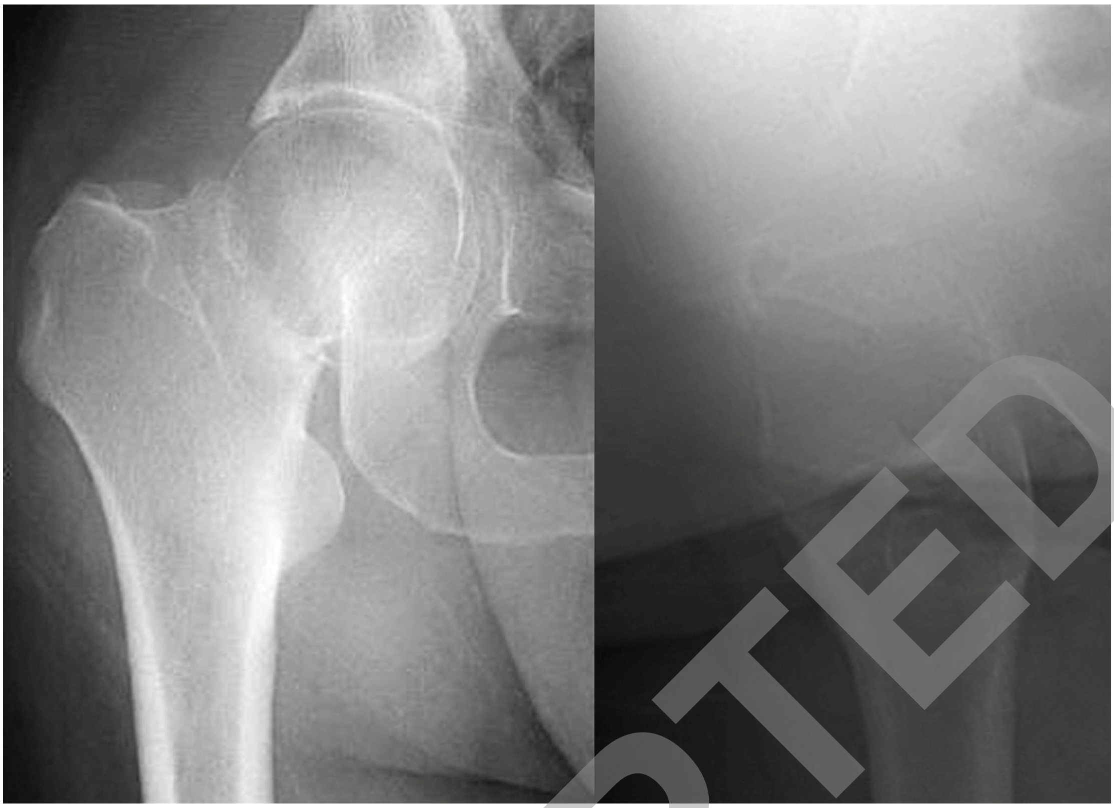

Hip capsule
Gluteus medius
(retracted)
Vastus lateralis
Greater trochanter

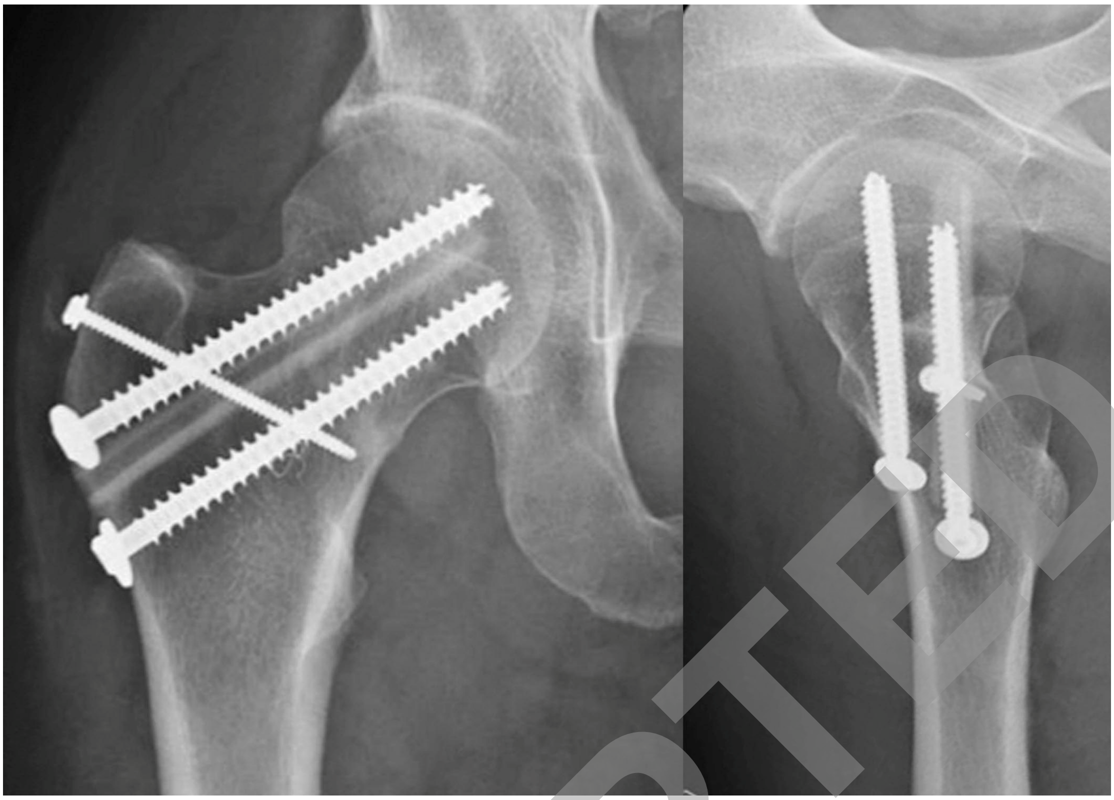


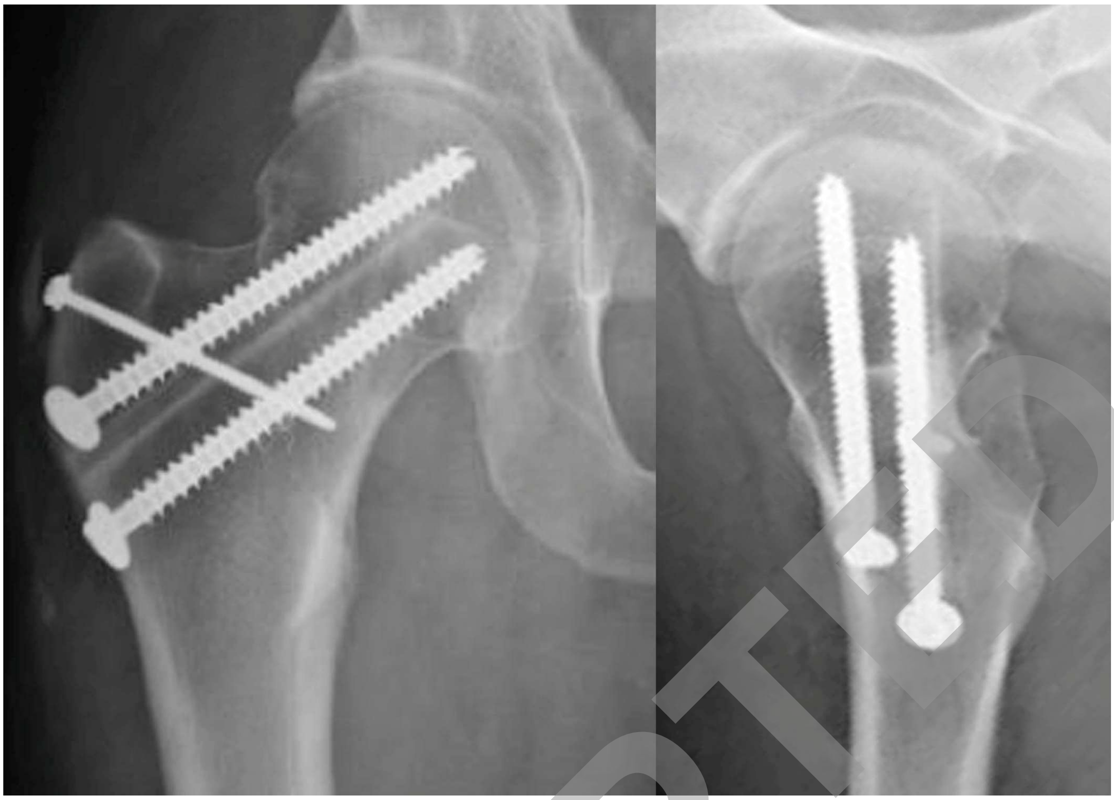


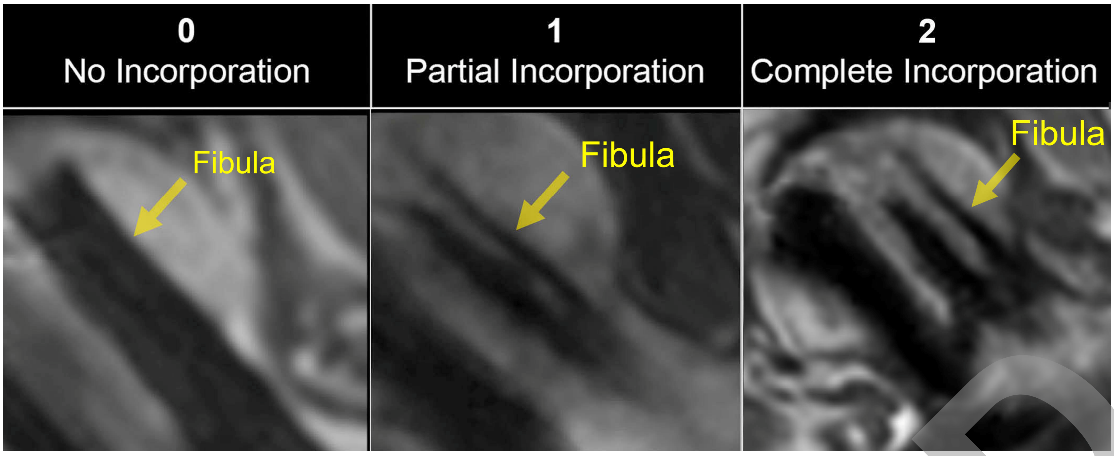








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Partial Incorporation
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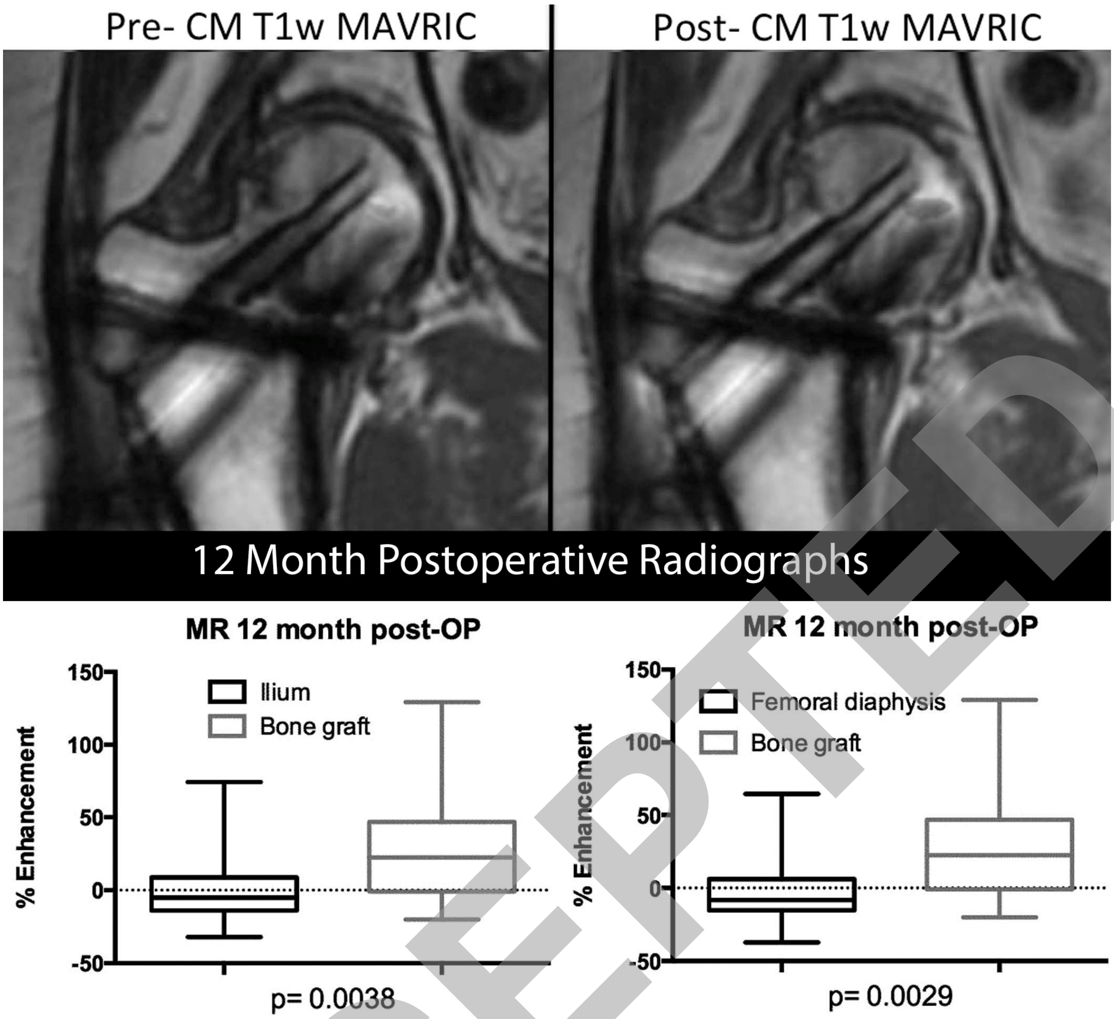
Pre- CM T1w MAVRIC
Post- CM T1w MAVRIC
12 Month Postoperative Radiographs
MR 12 month post-OP
% Enhancement
150
100
50
0
-50
Ilium
Bone graft
p= 0.0038
MR 12 month post-OP
% Enhancement
150
100
50
0
-50
Femoral diaphysis
Bone graft
p= 0.0029